

1                   IRRIGATED CATHETER HAVING A POROUS TIP ELECTRODE

FIELD OF THE INVENTION

5           The present invention is directed to an irrigated catheter having a porous tip electrode.

BACKGROUND OF THE INVENTION

10          Electrode catheters have been in common use in medical practice for many years. They are used to map electrical activity in the heart and to ablate sites of aberrant electrical activity.

15          In use, the electrode catheter is inserted into a major vein or artery, e.g., the femoral artery, and then guided into the chamber of the heart which is of concern. Within the heart, the ability to control the exact position and orientation of the catheter tip is critical and largely determines the usefulness of the catheter.

20          In certain applications, it is desirable to have the ability to inject and/or withdraw fluid through the catheter. One such application is a cardiac ablation procedure for creating lesions which interrupt errant electrical pathways in the heart. Traditionally, this has been accomplished with an irrigated tip catheter.

25          A typical ablation procedure involves the insertion of a catheter having a tip electrode at its distal end into a heart chamber. A reference electrode is provided, generally taped to the patient's skin. Radio frequency (RF) current is applied to the tip electrode, and flows through the surrounding media, i.e., blood and tissue, toward the reference electrode. The distribution of current depends on the amount of electrode surface in contact with the tissue, as compared to blood which has a higher conductivity than the tissue. Heating of the tissue occurs due to its electrical resistivity. The tissue is heated sufficiently to cause cellular destruction in the cardiac tissue resulting in

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1 formation of a lesion within the cardiac tissue which is  
electrically non-conductive. During this process, heating of  
the electrode also occurs as a result of conduction from the  
heated tissue to the electrode itself. If the electrode  
5 temperature becomes sufficiently high, possibly above 60°C, a  
thin transparent coating of dehydrated blood can form on the  
surface of the electrode. If the temperature continues to  
rise, this dehydrated layer of blood can become progressively  
thicker resulting in blood coagulation on the electrode  
10 surface. Because dehydrated biological material has a higher  
electrical resistance than endocardial tissue, impedance to  
the flow of electrical energy into the tissue also increases.  
If the impedance increases sufficiently, an impedance rise  
occurs and the catheter must be removed from the body and the  
15 tip electrode cleaned.

In a typical application of RF current to the  
endocardium, circulating blood provides some cooling of the  
ablation electrode. However, there is typically a stagnant  
area between the electrode and tissue which is susceptible to  
20 the formation of dehydrated proteins and coagulum. As power  
and/or ablation time increases, the likelihood of an impedance  
rise also increases. As a result of this process, there has  
been a natural upper bound on the amount of energy which can  
be delivered to cardiac tissue and therefore the size of RF  
25 lesions. Historically, RF lesions have been hemispherical in  
shape with maximum lesion dimensions of approximately 6 mm in  
diameter and 3 to 5 mm in depth.

In clinical practice, it is desirable to reduce or  
eliminate impedance rises and, for certain cardiac arrhythmias,  
30 to create larger lesions. One method for accomplishing this  
is to monitor the temperature of the ablation electrode and to  
control the RF current delivered to the ablation electrode  
based on this temperature. If the temperature rises above a  
pre-selected value, the current is reduced until the  
35 temperature drops below this value. This method has reduced

1 the number of impedance rises during cardiac ablations but has  
not significantly increased lesion dimensions. The results  
are not significantly different because this method continues  
to rely on the cooling effect of the blood which is dependent  
5 on the location within the heart and the orientation of the  
catheter to the endocardial surface.

Another method is to irrigate the ablation electrode,  
e.g., with physiologic saline at room temperature, to actively  
cool the ablation electrode instead of relying on the more  
10 passive physiological cooling provided by the blood. Because  
the strength of the RF current is no longer limited by the  
interface temperature, current can be increased. This results  
in lesions which tend to be larger and more spherical, usually  
measuring about 10 to 12 mm.

15 The clinical effectiveness of irrigating the ablation  
electrode is dependent upon the distribution of flow within  
the electrode structure and the rate of irrigation flow  
through the tip. Effectiveness is achieved by reducing the  
overall electrode temperature and eliminating hot spots in the  
20 ablation electrode which can initiate coagulum formation.  
More channels and higher flows are more effective in reducing  
overall temperature and temperature variations, i.e., hot  
spots. The coolant flow rate must be balanced against the  
amount of fluid that can be injected into the patient and the  
25 increased clinical load required to monitor and possibly  
refill the injection devices during a procedure. In addition  
to irrigation flow during ablation, a maintenance flow,  
typically a lower flow rate, is required throughout the  
procedure to prevent backflow of blood into the coolant  
30 passages. Thus, reducing coolant flow by utilizing it as  
efficiently as possible is a desirable design objective.

One method for designing an ablation electrode which  
efficiently utilizes coolant flow is the use of a porous  
material structure. One such design is described in U.S.  
35 Patent No. 6,405,078 to Moaddeb et al., the entire disclosure

1 of which is incorporated herein by reference. Moaddeb  
describes the use of sintered metal particles to create a  
porous tip electrode. In addition, Moaddeb uses a non-  
conductive insert implanted into the porous tip electrode for  
5 mounting a thermocouple, lead wire and/or irrigation tube  
within the porous tip electrode. However, during irrigation  
the sintered metal particles can disintegrate and break away  
from the electrode structure. Consequently, a desire arises  
for a porous electrode having increased structural integrity.

10 SUMMARY OF THE INVENTION

In one embodiment, the invention is directed to an  
irrigated catheter having a porous tip electrode. The  
catheter comprises a catheter body and a tip section. The  
15 catheter body has an outer wall, proximal and distal ends, and  
a lumen extending therethrough. The tip section comprises a  
segment of flexible tubing having proximal and distal ends and  
at least one lumen therethrough. The proximal end of the tip  
section is fixedly attached to the distal end of the catheter  
20 body. The porous tip electrode is fixedly attached to the  
distal end of the tubing of the tip section. The tip  
electrode comprises a porous material through which fluid can  
pass.

The porous tip electrode comprises sintered non-  
25 conductive material. The sintered material may be made from  
any suitable non-conductive polymer or ceramic material. The  
sintered particles comprise both small particles and large  
particles, the large particles having a mean diameter at least  
about 2.5 times greater, and preferably, about 4 times  
30 greater, than the mean diameter of the small particles. The  
use of differently sized particles helps control the porosity  
of the sintered material, promotes uniform flow of fluid  
through the porous material, and minimizes fluid pressure drop  
through the material. The porous tip electrode is covered  
35 with a thin metal coating that is webbed, or otherwise porous,

1 with openings through which fluid can pass to the outer  
surface of the tip electrode. The sintered polymeric or  
ceramic material has improved resistance to disintegration  
during irrigation. The metal coating improves overall  
5 structural stability of the tip electrode and serves as an  
electrode for conducting radio-frequency energy to the target  
tissue.

The catheter further comprises an irrigation tube having  
proximal and distal ends. The irrigation tube extends through  
10 the central lumen in the catheter body, with the distal end of  
the irrigation tube in fluid communication with the proximal  
end of the passage in the tip electrode. By this design, the  
fluid can flow through the irrigation tube, into the passage  
in the tip electrode and through the porous material and  
15 porous coating of the tip electrode to the outer surface of  
the tip electrode. A temperature sensing means is mounted in  
a blind hole in the tip electrode. A puller wire is mounted  
in the tip section. An electrode lead wire is electrically  
connected to the proximal end of the tip electrode.

#### 20 BRIEF DESCRIPTION OF THE DRAWINGS

These and other features and advantages of the present  
invention will be better understood by reference to the  
following detailed description when considered in conjunction  
25 with the accompanying drawings wherein:

**FIG. 1** is a side view of an embodiment of the catheter of  
the invention;

**FIG. 2** is a side cross-sectional view of a catheter body  
according to the invention, including the junction between the  
30 catheter body and tip section.;

**FIG. 3A** is a side cross-sectional view of a catheter tip  
section showing the lumens for the fluid passage and puller  
wire;

1           **FIG. 3B** is a side cross-sectional view of the catheter tip section of **FIG. 3A** showing the lumens for the fluid passage, thermocouple and electrode lead wires;

5           **FIG. 4** is a longitudinal cross-sectional view of the tip section illustrated in **FIGs. 3A** and **3B**;

**FIG. 5** is a side cross-sectional view of an alternative embodiment of a catheter body according to the invention having a side arm for an irrigation tube;

10          **FIG. 6** is a side view of a tip electrode according to the invention depicting one method of attaching the electrode lead wire to the tip electrode;

15          **FIG. 7** is a side cross-sectional view of a tip electrode according to the invention depicting the arrangement of the irrigation tube and temperature sensing means within the tip electrode;

**FIG. 8** is a close-up cross-sectional view of the distal section of the tip electrode taken along line 8-8 in **FIG. 7**;

20          **FIG. 9** is a side cross-sectional view of an alternative tip section according to the invention that houses an electromagnetic sensor; and

**FIG. 10** is a close-up view of a portion of the surface of the tip electrode depicting one embodiment of the porous coating disposed over the porous surface of the tip electrode.

## 25      DETAILED DESCRIPTION OF THE INVENTION

          In a particularly preferred embodiment of the invention, there is provided a steerable catheter having an irrigated tip. As shown in **FIGs. 1** to **4**, catheter **10** comprises an elongated catheter body **12** having proximal and distal ends, a tip section **14** at the distal end of the catheter body **12**, and a control handle **16** at the proximal end of the catheter body **12**.

35          With reference to **FIG. 2**, the catheter body **12** comprises an elongated tubular construction having a single, axial or central lumen **18**. The catheter body **12** is flexible, i.e.,

1 bendable but substantially non-compressible along its length.  
The catheter body 12 can be of any suitable construction and  
made of any suitable material. A presently preferred  
construction comprises an outer wall 22 made of a polyurethane  
5 or PEBAX. The outer wall 22 comprises an imbedded braided  
mesh of high-strength steel, stainless steel or the like to  
increase torsional stiffness of the catheter body 12 so that,  
when the control handle 16 is rotated, the tip section 14 of  
the catheter 10 will rotate in a corresponding manner. The  
10 outer diameter of the catheter body 12 is not critical, but is  
preferably no more than about 8 french, more preferably about  
7 french, still more preferably about 5 french. Likewise, the  
thickness of the outer wall 22 is not critical, but is thin  
enough so that the central lumen 18 can accommodate an  
15 irrigation tube, a puller wire, lead wires, and any other  
wires, cables or tubes. The inner surface of the outer wall  
22 is lined with a stiffening tube 20, which can be made of  
any suitable material, such as polyimide or nylon. The  
stiffening tube 20, along with the braided outer wall 22,  
20 provides improved torsional stability while at the same time  
minimizing the wall thickness of the catheter, thus maximizing  
the diameter of the central lumen 18. The outer diameter of  
the stiffening tube 20 is about the same as or slightly  
smaller than the inner diameter of the outer wall 22.  
25 Polyimide tubing is presently preferred for the stiffening  
tube 20 because it may be very thin walled while still  
providing very good stiffness. This maximizes the diameter of  
the central lumen 18 without sacrificing strength and  
stiffness. A particularly preferred catheter has an outer  
30 wall 22 with an outer diameter of from about 0.090 inches to  
about 0.098 inches and an inner diameter of from about 0.061  
inches to about 0.065 inches and a polyimide stiffening tube  
20 having an outer diameter of from about 0.060 inches to  
about 0.064 inches and an inner diameter of from about 0.051  
35 inches to about 0.056 inches.

1 As shown in **FIGs. 3A, 3B, and 4**, the tip section **14**  
comprises a short section of tubing **19** having three lumens **30**,  
**32** and **34**. The tubing **19** is made of a suitable non-toxic  
material that is preferably more flexible than the catheter  
5 body **12**. A presently preferred material for the tubing **19** is  
braided polyurethane, i.e., polyurethane with an imbedded mesh  
of braided high-strength steel, stainless steel or the like.  
The outer diameter of the tip section **14**, like that of the  
catheter body **12**, is preferably no greater than about 8  
10 french, more preferably about 7 french, still more preferably  
about 5 french. The size of the lumens is not critical. In a  
particularly preferred embodiment, the tip section **14** has an  
outer diameter of about 7 french (0.092 inches) and the first  
lumen **30** and second lumen **32** are generally about the same  
15 size, each having a diameter of from about 0.020 inches to  
about 0.024 inches, preferably about 0.022 inches, with the  
third lumen **34** having a slightly larger diameter of from about  
0.032 inches to about 0.038 inches, preferably about 0.036  
inches.

20 A preferred means for attaching the catheter body **12** to  
the tip section **14** is illustrated in **FIG. 2**. The proximal end  
of the tip section **14** comprises an outer circumferential notch  
**24** that receives the inner surface of the outer wall **22** of the  
catheter body **12**. The tip section **14** and catheter body **12** are  
25 attached by adhesive (e.g. polyurethane glue) or the like.  
Before the tip section **14** and catheter body **12** are attached,  
however, the stiffening tube **20** is inserted into the catheter  
body **12**. The distal end of the stiffening tube **20** is fixedly  
attached near the distal end of the catheter body **12** by  
30 forming a glue joint (not shown) with polyurethane glue or the  
like. Preferably, a small distance, e.g., about 3 mm, is  
provided between the distal end of the catheter body **12** and  
the distal end of the stiffening tube **20** to permit room for  
the catheter body **12** to receive the notch **24** of the tip  
35 section **14**. A force is applied to the proximal end of the

1 stiffening tube 20, and, while the stiffening tube 20 is under  
compression, a first glue joint (not shown) is made between  
the stiffening tube 20 and the outer wall 22 by a fast drying  
glue, e.g. Super Glue®. Thereafter, a second glue joint (not  
5 shown) is formed between the proximal ends of the stiffening  
tube 20 and outer wall 22 using a slower drying but stronger  
glue, e.g. polyurethane.

At the distal end of the tip section 14 is a tip  
electrode 36. Preferably, the tip electrode 36 has a diameter  
10 about the same as the outer diameter of the tubing 19. The  
tip electrode 36 is formed of any suitable non-conductive  
polymer, such as polyethylene or Teflon®, or ceramic material,  
in which holes are drilled. The porous non-conductive  
material can be made using any conventional technique. For  
15 example, the porous non-conductive material can be machined  
from a rod of the material. Preferably, however, the non-  
conductive polymer comprises sintered polymer particles 86  
formed from polyethylene or Teflon®, as best depicted in FIG.  
8. As used herein, the term "sinter" refers to the process of  
20 bonding adjacent particles in a powder mass or compacting the  
particles by heating them to a temperature below the melting  
point of the main constituent at a predetermined and closely  
controlled time-temperature regime, including heating and  
cooling phases, in a protective atmosphere. The sintered  
25 polymer particles 86 permit passage of a cooling fluid through  
the tip electrode, as described in more detail below. The  
porosity of the sintered material is controlled by the amount  
of particle compacting in the mold or glue, the particle size,  
and the particle distribution.

30 A particularly preferred sintering process involves  
providing polyethylene or Teflon® powder particles in a  
certain sieve fraction, e.g., in the range of from about 5  
microns to about 250 microns. The particles are preferably in  
the range of from about 10 microns to about 100 microns. In a  
35 particularly preferred embodiment, at least two different

1 sized particles can be provided. For example, particles in  
the range of from about 15 microns to about 30 microns, and  
more preferably about 20 microns, in combination with  
particles in the range of from about 80 microns to about 110  
5 microns, and more preferably about 100 microns, could be used.  
When two different sized particles are used, preferably the  
larger particles have a mean diameter at least about 2.5 times  
greater than the mean diameter of the smaller particles, and  
more preferably at least about 4 times greater.  
10 Alternatively, a single particle size can be used, which can  
give a denser packing and result in a higher pressure drop  
across the porous electrode. Whatever polymer is used, the  
particles are preferably rounded, and more preferably  
spherical, so as to provide a tip electrode surface that is  
15 not rough. However, the particles can be irregularly shaped,  
i.e. having differing shapes, which is a low cost alternative.

In a preferred process, the particles are put into a  
mold, such as a ceramic mold, having the desired electrode  
shape. If desired, the particles can be mixed with a  
20 suitable binder prior to being put into the mold. When a  
binder is used, the mold containing the binder and particles  
is placed into a low temperature oven and heated to a  
temperature sufficient to evaporate the binder. The particles  
are then sintered under vacuum or air at a temperature ranging  
25 from about 80°C to about 160°C, although the temperature can  
vary depending on the composition of the porous polymer.  
However, the temperature should be below the melting point of  
the composition. The resulting tip electrode is then removed  
from the mold and assembled onto the flexible tubing of the  
30 tip section.

A tip electrode prepared in accordance with this method  
is depicted in **FIG. 8**. In particular, **FIG. 8** illustrates the  
porosity of the tip electrode when particles of different  
sizes are used. Although the drawings of the tip electrode,  
35 such as **FIGs. 3A** and **3B**, do not depict the porous sintered

1 material in detail, it is to be understood that where the body  
of the tip electrode is described as being made of a porous  
sintered material, it appears generally as depicted in **FIG. 8**.  
The drawings, such as **FIGs. 3A** and **3B**, are provided to more  
5 clearly show the additional components in the tip section.

As shown in **FIGs. 3A** and **3B**, the tip electrode **36** has two  
cavities extending therein, namely a primary fluid passage **35**  
and a blind hole **31** that correspond in size and location to  
the lumens **34** and **30**, respectively, in the tip section **14**.  
10 The primary fluid passage **35** extends substantially all the way  
through the sintered material of the tip electrode **36**,  
preferably ending just before the distal end of the tip  
electrode **36**. The blind hole **31** extends only a part of the  
way through the sintered material of the tip electrode **36**,  
15 preferably about half the length of the tip electrode **36** or  
less. For example, for a 3.5 mm tip electrode **36**, the blind  
hole **31** is about 0.088 inches long.

Disposed over the surface of the porous tip electrode is  
a thin metal coating **84**, as depicted in **FIG. 10**. The metal  
20 coating **84** serves to impart improved structural integrity to  
the porous tip electrode **36** while also serving as an electrode  
for distributing radio-frequency energy to the target tissue.  
The metal coating **84** can be made of any conductive metal, e.g.  
platinum or gold. Preferably, the metal coating **84** is made of  
25 a platinum-iridium alloy, e.g. 90% Platinum/10% Iridium,  
applied to the surface of the porous tip electrode **36** by a  
deposition process impregnating a thin layer of platinum-  
iridium alloy onto the porous surface of the tip electrode **36**.  
The thickness of the metal coating **84** may vary as desired, but  
30 is sufficiently thin to maintain a porous electrode surface,  
and sufficiently thick to maintain a conductive surface. For  
example, the metal coating **84** may have a thickness ranging  
from 0.2  $\mu\text{m}$  to about 2  $\mu\text{m}$ . Preferably, as shown in **FIG. 10**,  
the metal coating **84** is webbed or otherwise porous with

1 openings **85** in the metal coating **84** through which irrigation fluids can pass.

5 A preferred tip electrode has a length ranging from about 2.5 mm to about 8 mm, preferably about 3.5 mm. Preferably, the tip electrode **36** is attached to the tubing **19** by polyurethane glue or the like. The wires and tubes that extend into the tip electrode **36**, described in more detail below, help to keep the tip electrode in place on the tubing **19** of the tip section **14**.

10 In the embodiment shown in **FIGs. 3A** and **3B**, there are three ring electrodes **39** mounted on the tubing **19** proximal to the tip electrode **36**. It is understood that the presence and number of ring electrodes **39** may vary as desired. Each ring electrode **39** is slid over the tubing **19** and fixed in place by glue or the like. The ring electrodes **39** can be made of any suitable material, and are preferably machined from platinum-iridium bar (90% platinum/10% iridium).

15 The tip electrode **36** and ring electrodes **39** are each connected to a separate lead wire **44**. The lead wires **44** extend through the first lumen **30** of tip section **14**, the central lumen **18** of the catheter body **12**, and the control handle **16**, and terminate at their proximal ends in an input jack (not shown) that may be plugged into an appropriate monitor (not shown). The portion of the lead wires **44** extending through the central lumen **18** of the catheter body **12**, control handle **16** and proximal end of the tip section **14** may be enclosed within a protective sheath **49**, which can be made of any suitable material, preferably polyimide. The protective sheath **49** is preferably anchored at its distal end to the proximal end of the tip section **14** by gluing it in the first lumen **30** with polyurethane glue or the like. The lead wires **44** are attached to the tip electrode **36** and ring electrodes **39** by any conventional technique. For example, as described below, the tip electrode **36**, in one embodiment, may have a distal section **70** having a greater diameter than the

1 diameter of proximal section 68. In this embodiment, as  
depicted in **FIG. 6**, connection of a lead wire 44 to the tip  
electrode is accomplished, for example, by coiling the lead  
wire 44 around the proximal portion of the tip electrode 36  
5 and gluing it in place to the metal coating 84 with  
polyurethane glue or the like.

Connection of a lead wire 44 to a ring electrode 39 is  
preferably accomplished by first making a small hole through  
the tubing 19. Such a hole can be created, for example, by  
10 inserting a needle through the tubing 19 and heating the  
needle sufficiently to form a permanent hole. A lead wire 44  
is then drawn through the hole by using a microhook or the  
like. The ends of the lead wire 44 are then stripped of any  
coating and soldered or welded to the underside of the ring  
15 electrode 39, which is then slid into position over the hole  
and fixed in place with polyurethane glue or the like.

An irrigation tube is provided within the catheter body  
12 for infusing fluids, e.g. saline, to cool the tip electrode  
36. The irrigation tube may be made of any suitable material,  
20 and is preferably made of polyimide tubing. A preferred  
irrigation tube has an outer diameter of from about 0.032  
inches to about 0.036 inches and an inner diameter of from  
about 0.027 inches to about 0.032 inches.

With reference to **FIGS. 2** and **3A**, the irrigation tube  
25 comprises multiple tube segments. A first irrigation tube  
segment 46 extends through the central lumen 18 of the  
catheter body 12 and terminates in the proximal end of the  
third lumen 34 of the tip section 14. The distal end of the  
first irrigation tube segment 46 is anchored in the third  
30 lumen 34 by polyurethane glue or the like. The proximal end  
of the first irrigation tube segment 46 extends through the  
control handle 16 and terminates in a luer hub 47 or the like  
at a location proximal to the control handle. A second  
irrigation tube segment 48 is provided at the distal end of  
35 the third lumen 34 and extends into the primary fluid passage

1 35 of the tip electrode 36. The second irrigation tube  
segment 48 is anchored by polyurethane glue or the like within  
the third lumen 34 of the tip section 14 and in the primary  
fluid passage 35. The second irrigation tube segment 48  
5 provides additional support to maintain the tip electrode 36  
mounted on the tubing 19. In practice, fluid is injected into  
the first irrigation tube segment 46, through the third lumen  
34, through the second irrigation tube segment 48, into the  
primary fluid passage 35 of the tip electrode 36, and out  
10 through the porous material of the tip electrode. Because the  
primary fluid passage 35 extends distally a greater length  
than the blind hole 31, the fluid can pass outwardly on all  
sides of the distal end of the primary fluid passage 35.

The fluid introduced through the catheter is preferably a  
15 biologically compatible fluid, and may be in a gaseous or  
liquid state. Suitable fluids include saline, water, carbon  
dioxide, nitrogen, and helium. In addition to, or instead of,  
being used to cool the tip electrode, the infused fluid also  
forms a buffer layer to maintain biological materials, such as  
20 blood, at a distance from the tip electrode, thereby  
minimizing contact of the tip electrode with the biological  
material. This buffer layer reduces coagulation of biological  
materials and regulates the impedance or resistance to energy  
transfer of the tissue near the tip electrode during ablation.

25 The rate of fluid flow through the catheter may be  
controlled by any suitable fluid infusion pump or by pressure.  
A suitable infusion pump is the FLOGARD™ available from  
Baxter. The rate of fluid flow through the catheter  
preferably ranges from about 0.5 ml/min to about 30 ml/min,  
30 more preferably from about 5 ml/min to about 15 ml/min.  
Preferably, the fluid is maintained at about room temperature.

As shown in FIG. 7, a temperature sensing means 41 is  
provided for the tip electrode 36 and, if desired, the ring  
electrodes 39. Any conventional temperature sensing means 41,  
35 e.g., a thermocouple or thermistor, may be used. With

1 reference to **FIG. 3B**, a preferred temperature sensing means **41**  
for the tip electrode **36** comprises a thermocouple formed by a  
wire pair. One wire of the wire pair is a copper wire **41a**,  
e.g., a number **40** copper wire. The other wire of the wire  
5 pair is a constantan wire **43**, which gives support and strength  
to the wire pair. The wires **41a** and **43** of the wire pair are  
electrically isolated from each other except at their distal  
ends where they contact each other and are twisted together,  
covered with a short piece of plastic tubing **45**, e.g.  
10 polyimide, and covered with epoxy. The plastic tubing **45** is  
then attached by polyurethane glue or the like in the first  
blind hole **31** of the tip electrode **36**. The wires **41a** and **43**  
extend through the first lumen **30** in the tip section **14**.  
Within the catheter body **12**, the wires **41a** and **43** may extend  
15 through the protective sheath **49** with the lead wires **44**. The  
wires **41a** and **43** then extend out through the control handle **16**  
and to a connector (not shown) connectable to a temperature  
monitor (not shown).

Alternatively, the temperature sensing means **41** may be a  
20 thermistor. A suitable thermistor for use in the present  
invention is Model No. AB6N2-GC14KA143E/37C sold by  
Thermometrics (New Jersey). The temperature sensing means may  
also be used as a feedback system to adjust the flow rate of  
the fluid through the catheter to maintain a desired  
25 temperature at the tip electrode.

A puller wire **50** extends through the catheter body **12**, is  
anchored at its proximal end to the control handle **16**, and is  
anchored at its distal end to the tip section **14**. The puller  
wire **50** is made of any suitable metal, such as stainless steel  
30 or Nitinol, and is preferably coated with Teflon® or the like.  
The coating imparts lubricity to the puller wire **50**. The  
puller wire **50** preferably has a diameter ranging from about  
0.006 inches to about 0.010 inches.

A compression coil **52** is situated within the catheter  
35 body **12** in surrounding relation to the puller wire **50**. The

1 compression coil 52 extends from the proximal end of the  
catheter body 12 to the proximal end of the tip section 14.  
The compression coil 52 is made of any suitable metal,  
preferably stainless steel. The compression coil 52 is  
5 tightly wound on itself to provide flexibility, i.e., bending,  
but to resist compression. The inner diameter of the  
compression coil 52 is preferably slightly larger than the  
diameter of the puller wire 50. The Teflon® coating on the  
puller wire 50 allows it to slide freely within the  
10 compression coil 52. If desired, particularly if the lead  
wires 44 are not enclosed by a protective sheath 49, the outer  
surface of the compression coil 52 can be covered by a  
flexible, non-conductive sheath, e.g., made of polyimide  
tubing, to prevent contact between the compression coil 52 and  
15 any other wires within the catheter body 12.

The compression coil 52 is anchored at its proximal end  
to the proximal end of the stiffening tube 20 in the catheter  
body 12 by glue joint 51 and at its distal end to the tip  
section 14 by glue joint 53. Both glue joints 52 and 53  
20 preferably comprise polyurethane glue or the like. The glue  
may be applied by means of a syringe or the like through a  
hole made between the outer surface of the catheter body 12  
and the central lumen 18. Such a hole may be formed, for  
example, by a needle or the like that punctures the outer wall  
25 22 of the catheter body 12 and stiffening tube 20 which is  
heated sufficiently to form a permanent hole. The glue is  
then introduced through the hole to the outer surface of the  
compression coil 52 and wicks around the outer circumference  
to form a glue joint about the entire circumference of the  
30 compression coil 52.

The puller wire 50 extends into the second lumen 32 of  
the tip section 14. The puller wire 50 is anchored at its  
distal end to the tip section 14. Preferably, an anchor is  
fixedly attached to the distal end of the puller wire 50, as  
35 depicted in FIGs. 3A and 9. The anchor is preferably formed

1 by a metal tube **55**, e.g. a short segment of hypodermic stock,  
which is fixedly attached, e.g. by crimping, to the distal end  
of the puller wire **50**. The tube **55** has a section that extends  
a short distance beyond the distal end of the puller wire **50**.  
5 A cross-piece **53** made of a small section of stainless steel  
ribbon or the like is soldered or welded in a transverse  
arrangement to the distal end of the tube section **55**, which is  
flattened during the operation. This creates a T-bar anchor.  
A notch is created in the side of the tip section **14**,  
10 resulting in an opening into the second lumen **32** into which  
the puller wire **50** extends. The anchor lies partially within  
the notch. Because the length of the ribbon forming the  
cross-piece **53** is longer than the diameter of the opening into  
the lumen **32**, the anchor cannot be pulled completely into the  
15 lumen **32**. The notch is then sealed with polyurethane glue or  
the like to give a smooth outer surface. Within the second  
lumen **32** of the tip section **14**, the puller wire **50** extends  
through a plastic, preferably Teflon® sheath **56**, which  
prevents the puller wire **50** from cutting into the wall of the  
20 tubing **19** when the tip section is deflected.

In an alternative arrangement, as shown in **FIG. 5**, a  
single lumen side arm **58** is fluidly connected to the central  
lumen **18** near the proximal end of the catheter body **12**. The  
first irrigation tube segment **46** extends through the catheter  
25 body **12** and out the side arm **58**, where it terminates in a luer  
hub (not shown) or the like. The side arm **58** is preferably  
made of the same material as the outer wall **22**, but preferably  
has a greater thickness, e.g. 0.0275 inches. Where the side  
arm **58** meets the catheter body **12**, a molded joint can be  
30 provided to provide additional strength and support. The  
molded joint can be made of any suitable biocompatible  
material, and is preferably made of polyurethane.

Longitudinal movement of the puller wire **50** relative to  
the catheter body **12**, which results in deflection of the tip  
35 section **14**, is accomplished by suitable manipulation of the

1 control handle 16. A suitable control handle for use with the  
present invention is described in U.S. Patent No. 6,120,476,  
the disclosure of which is incorporated herein by reference.

5 In another preferred embodiment according to the  
invention, an electromagnetic sensor 64 is provided in the  
distal end of the tip section 14. As shown in FIG. 9, in this  
embodiment the tip electrode 36 is connected to the tubing 19  
of the tip section 14 by means of a plastic housing 66,  
preferably made of polyetheretherketone (PEEK). The tip  
10 electrode 36 has a proximal section 68 and a distal section  
70. The proximal section 68 of the tip electrode 36 has an  
outer diameter less than the outer diameter of the distal  
section 70. Thus, in the depicted embodiment, the proximal  
section 68 forms a recessed stem that fits inside the distal  
15 end of the plastic housing 66, and the distal section 70 is  
exposed. The proximal section 68 is bonded to the housing 66  
by polyurethane glue or the like. The proximal end of the  
plastic housing 66 is bonded with polyurethane glue or the  
like to the distal end of the tubing 19 of the tip section 14.  
20 Preferably, the plastic housing 66 is about 1 cm long.

In this embodiment, the tip electrode 36 preferably has a  
total length ranging from about 6 mm to about 9 mm, more  
preferably about 7 mm. For a 7 mm long tip electrode, the  
distal section 70 and proximal section 68 each preferably have  
25 a length of about 3.5 mm. The proximal section 68 is formed  
of a solid metal material. The distal section 70 is formed of  
a porous material, as described above. However, the tip  
electrode 36 could be modified so that a portion of the  
proximal section 68, which is formed of a solid material, is  
30 exposed along with the distal section 70, which is formed of a  
porous material. Alternatively, a portion of the distal  
section 70 could form a part of the stem that extends into the  
housing 66. However, in the preferred embodiment, the entire  
porous distal section 70 is exposed and the entire solid  
35 proximal section 68 is contained within the housing 66.

1           A generally hollow cavity 72 is formed in the proximal  
end of the proximal section 68 of the tip electrode 36. The  
electromagnetic sensor 64 is mounted partially in the plastic  
housing 66, partially in the cavity 72, and partially in the  
5       flexible tubing 19, in a manner similar to that described in  
U.S. Patent No. 6,120,476, the disclosure of which is  
incorporated herein by reference.

          The tip electrode 36 has a fluid passage 35 and a blind  
hole 31 that extend longitudinally from the cavity 72. The  
10       second irrigation tube segment 48, puller wire 50,  
thermocouple wires 41 and 43, and tip electrode lead wire 44  
are mounted in the tip electrode. The electromagnetic sensor  
64 is connected to an electromagnetic sensor cable 65, which  
extends through the third lumen 34 of the tip section 14,  
15       through the central lumen 18 of the catheter body 12, and into  
the control handle 16. The electromagnetic sensor cable 65  
then extends out the proximal end of the control handle 16  
within an umbilical cord (not shown) to a sensor control  
module (not shown) that houses a circuit board (not shown).  
20       Alternatively, the circuit board can be housed within the  
control handle 16, for example, as described in U.S. Patent  
No. 5,964,757, the disclosure of which is incorporated herein  
by reference. The electromagnetic sensor cable 65 comprises  
multiple wires encased within a plastic covered sheath. In  
25       the sensor control module, the wires of the electromagnetic  
sensor cable are connected to the circuit board. The circuit  
board amplifies the signal received from the electromagnetic  
sensor and transmits it to a computer in a form understandable  
by the computer by means of the sensor connector at the  
30       proximal end of the sensor control module. Also, because the  
catheter is designed for single use only, the circuit board  
preferably contains an EPROM chip which shuts down the circuit  
board approximately 24 hours after the catheter has been used.  
This prevents the catheter, or at least the electromagnetic  
35       sensor, from being used twice.       Suitable electromagnetic

1 sensors for use with the present invention are described, for  
example, in U.S. Patent Nos. 5,558,091, 5,443,489, 5,546,951,  
5,568,809 and 5,391,199 and International Publication No. WO  
95/02995, the disclosures of which are incorporated herein by  
5 reference. A preferred electromagnetic sensor **64** has a length  
of from about 6 mm to about 7 mm and a diameter of about 1.3  
mm.

Preferably, in this embodiment, the catheter body does  
not comprise a stiffening tube **20**, because additional space is  
10 needed within the central lumen **10** to include the  
electromagnetic sensor cable. The catheter body in this  
embodiment has an outer diameter preferably no greater than  
about 8 french, more preferably from about 7 french to about  
7.5 french, and if desired, no greater than about 5 french.

15 In the above-described embodiments, the tip electrode is  
described as having a fluid passage and a blind hole. As  
would be recognized by one skilled in the art, the tip  
electrode could have only a fluid passage into which all of  
the tubes, wires, etc. extend. However, such a design is less  
20 desirable because the thermocouple would be in direct contact  
with the fluid, which can result in an inaccurate temperature  
reading.

If desired, the catheter can be multidirectional, i.e.,  
having two or more puller wires to enhance the ability to  
25 manipulate the tip section in more than one direction or to  
form two or more different curves. Such a design is described  
in U.S. Patent No. 6,123,699, the disclosure of which is  
incorporated herein by reference.

The preceding description has been presented with  
30 reference to presently preferred embodiments of the invention.  
Workers skilled in the art and technology to which this  
invention pertains will appreciate that alterations and  
changes in the described structure may be practiced without  
meaningfully departing from the principle, spirit and scope of  
35 this invention. Accordingly, the foregoing description should

1 not be read as pertaining only to the precise structures  
described and illustrated in the accompanying drawings, but  
rather should be read consistent with and as support for the  
following claims, which are to have their fullest and fairest  
5 scope.

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